Energy Implications of Refrigerated Warehouse Practices

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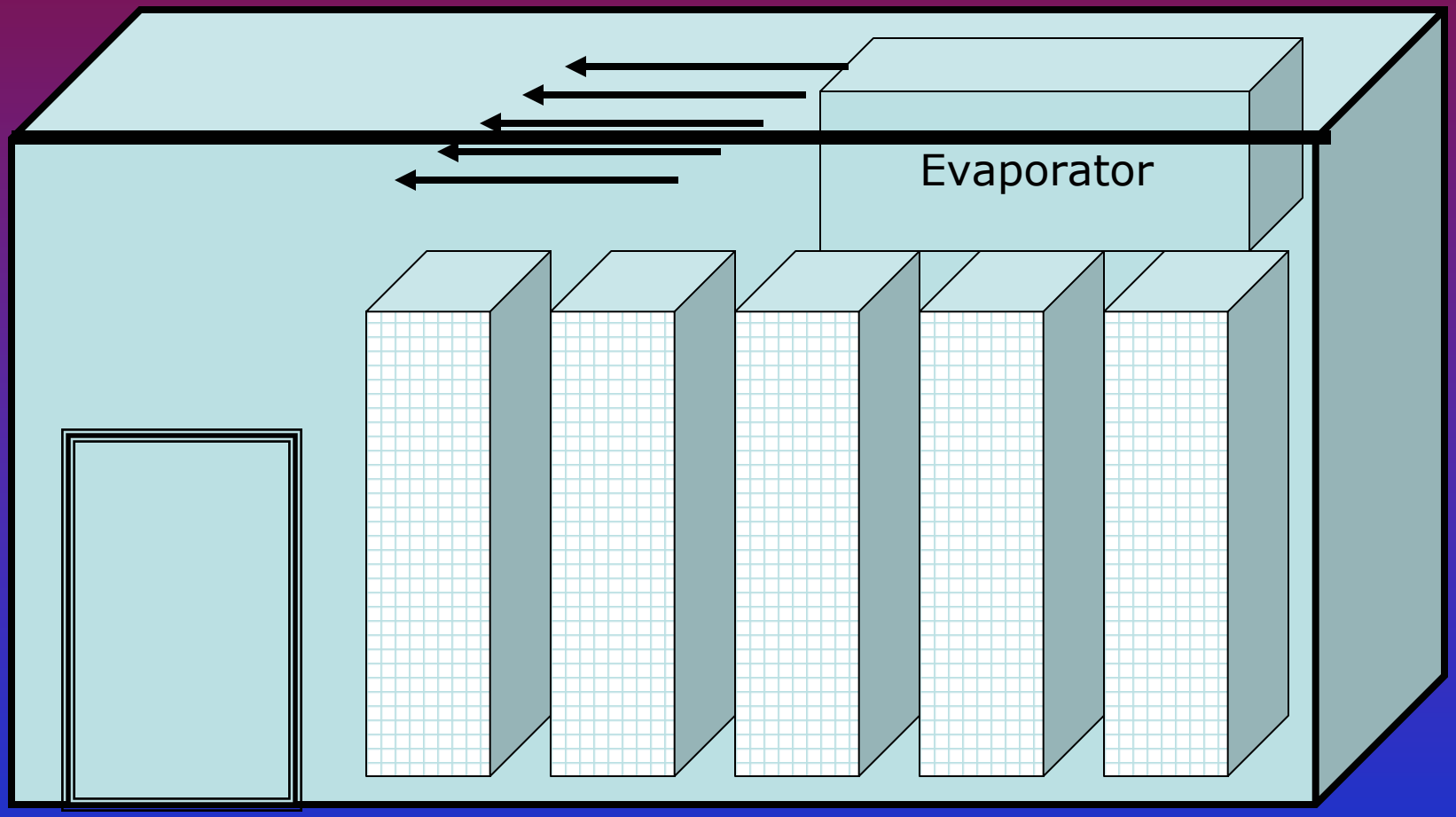
A Freezer Warehouse



Turn off refrigeration during periods of peak electric demand to reduce energy costs?

Implications on

- energy savings
- food quality

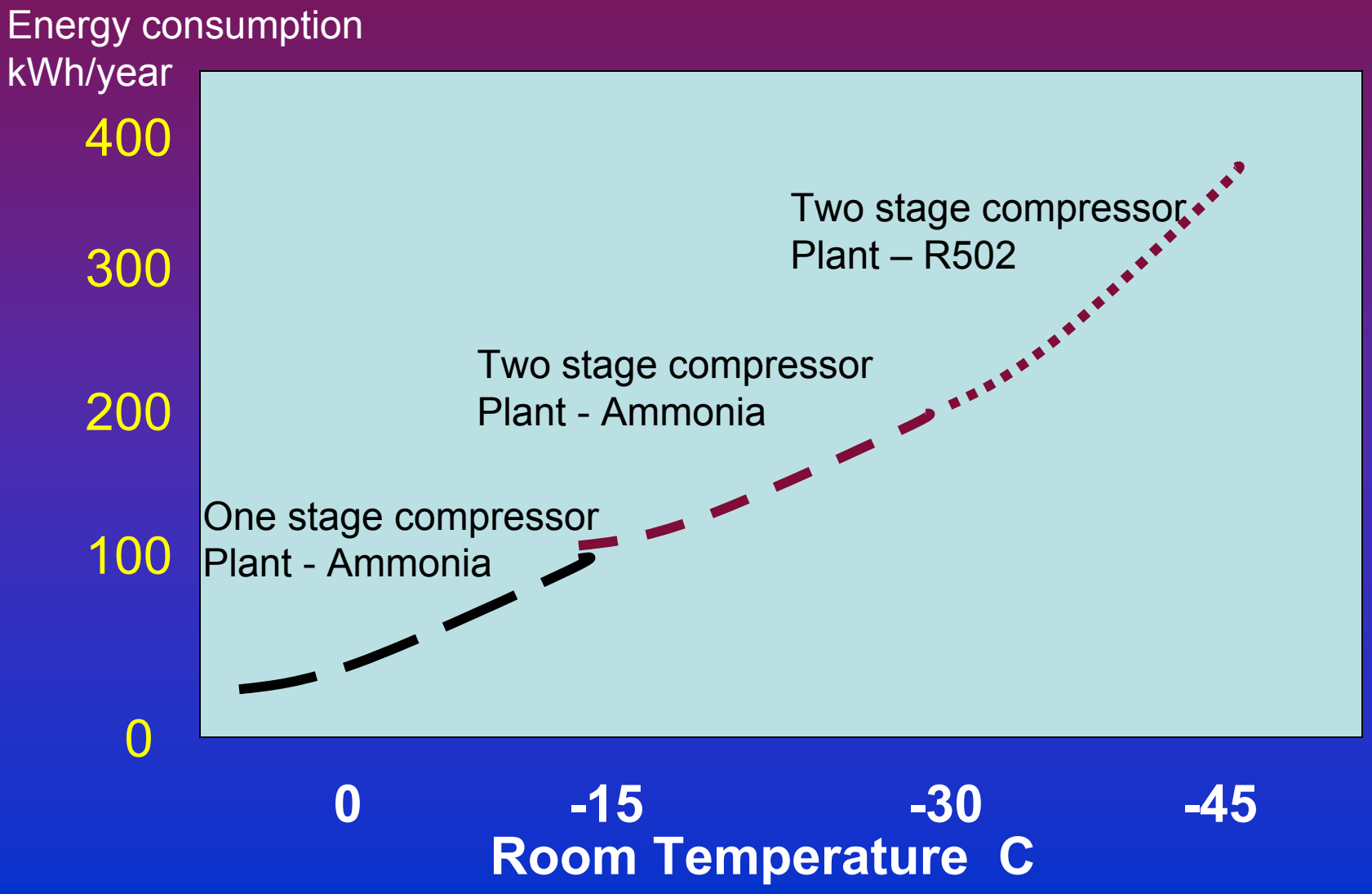
Frozen Food Quality

- Frozen food quality is sensitive to storage temperature and fluctuations in temperature.
- Interruption in refrigeration system operation may result in negative impacts on product quality.
  - accelerated deterioration reactions at elevated temperatures,
  - the growth in ice crystal size occurring during the temperature fluctuations.

Temperature Abused Frozen Broccoli

Temperature Abused Frozen Shrimp

Energy Consumption vs. Storage Temperature



Variables to Consider

- Volume of refrigerated warehouse
- Amount of frozen food in warehouse
- Length and timing of refrigeration system downtime
- Amount of air exchange occurring during product movement in and out of facility
- Timing of refrigeration down periods in relation to timing of product movement
- Temperature of product entering storage

Preliminary Analysis

- Analysis conditions include:
  1. A 3 million cubic foot warehouse
  2. Warehouse contains 30 million pounds of frozen food.
  3. Product movement creates 1000 warehouse door openings per 24 hour day; each opening cause an exchange of 250 cubic feet of air.
  4. Product storage is at -18 C (0 F) and air exchange is 50 F

Preliminary Analysis

- Analysis conditions include

  1. Product pallets contain product with 75 cubic feet and 1500 pounds.

  2. Individual product packages on the pallet are 30 pounds and occupy one-half cubic foot.

  3. Each package has 2 square feet of area exposed to air.

General Results of Analysis

- In a typical warehouse, product will occupy about one-sixth of the volume.
- About one-tenth of the air volume within the product storage environment will be exchanged within a 24 hour period.
- If air exchange does not occur during period of downtime, storage temperature will not change.
- When air exchange occurs during refrigeration downtime, storage air temperature may increase from 0 F to 5 F and product temperature may reach 4 F within 10 hours.

Influence of Incoming Product Temperature

Incoming Product Temperature	Warehouse Air Temperature	Product Temperature After 10 hour
0 F	5 F	4
5	8	6
10	12	9
15	16	12

Note – these are preliminary estimates, and include assumptions about the thermal energy exchanges within the warehouse.

Impact of Product Temperature

- A significant factor to consider is the temperature of the frozen product entering the storage.
- When incoming product is at temperatures above 0 F, impact of refrigeration downtime becomes more significant.
- The thermal capacity of frozen product has significant impact on the temperature in the warehouse.
- The addition of higher temperature product tends to magnify the impacts of fluctuations in air temperature.

Additional Analysis Needed

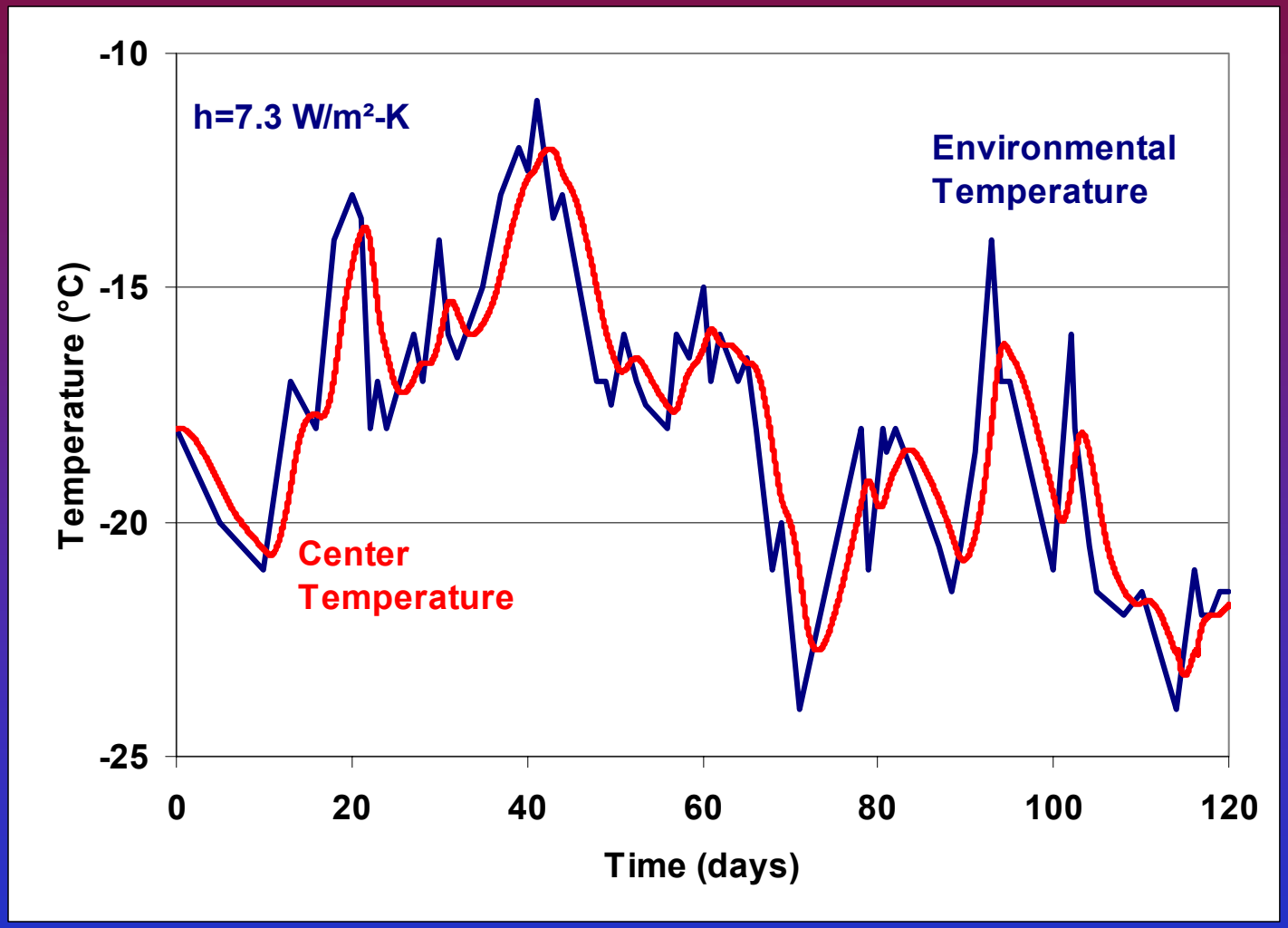
- The quantity of product in the warehouse should be varied and the impact needs to be evaluated.
- The volumes of air exchanged during product movement must be measured.
- The length of time required for product and air to reach an equilibrium temperature requires more careful analysis.

Future Tasks

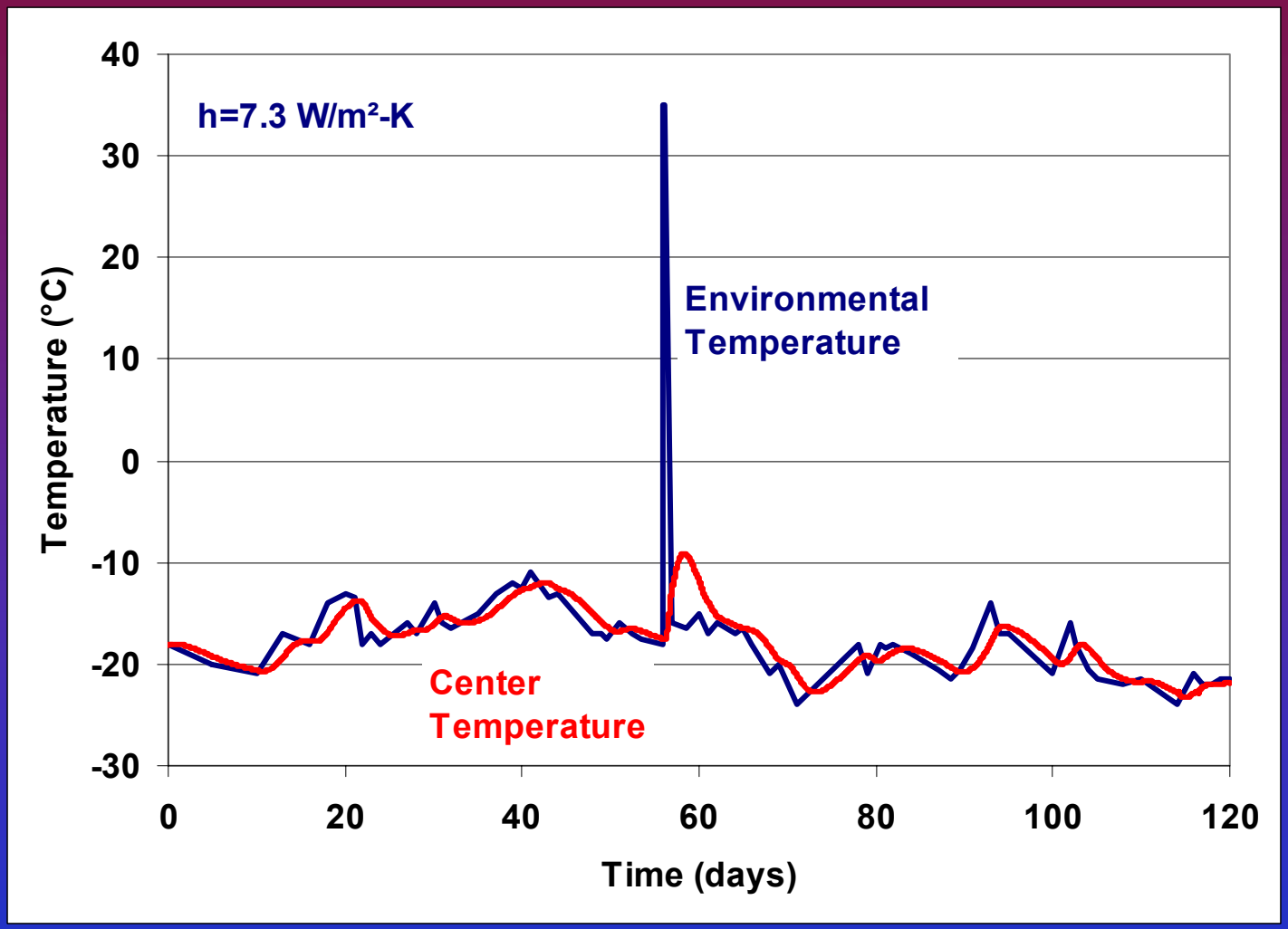
- Develop a simulation model for prediction of frozen food temperature in a warehouse during refrigeration downtime
- To use simulation model to evaluate the influence of
  - Warehouse capacity
  - Quantity of product in warehouse
  - Temperature of air and product
  - Volume of air exchange
  - Temperature of product entering
  - Amount of air movement
  - Fan operation
- To validate the model by experimental measurements in a commercial warehouse
- To provide a user-friendly program for warehouse operators
- To develop recommendations for warehouse management regarding downtime

Simulation Model

- Industrial Scale Food Freezing and Thawing Simulation
  - J. Mannapperuma, R. P. Singh, F. Erdogdu
  - WFLO - Virginia



1.2*1.2*1.2 m³ pallet size



1.2*1.2*1.2 m³ pallet size

Deterioration Modes of Frozen Foods

- Frozen Fruits and Vegetables
  - Loss of nutrients (vitamins)
  - Loss of texture (temperature abuse)
  - Loss of flavor (lipoxygenase, peroxidase)
  - Loss of tissue moisture (forming package ice)
  - Discoloration
- Frozen concentrated juices
  - Loss of nutrients (vitamins)
  - Loss of flavor
  - Discoloration
  - Yeast growth (upon temperature abuse)

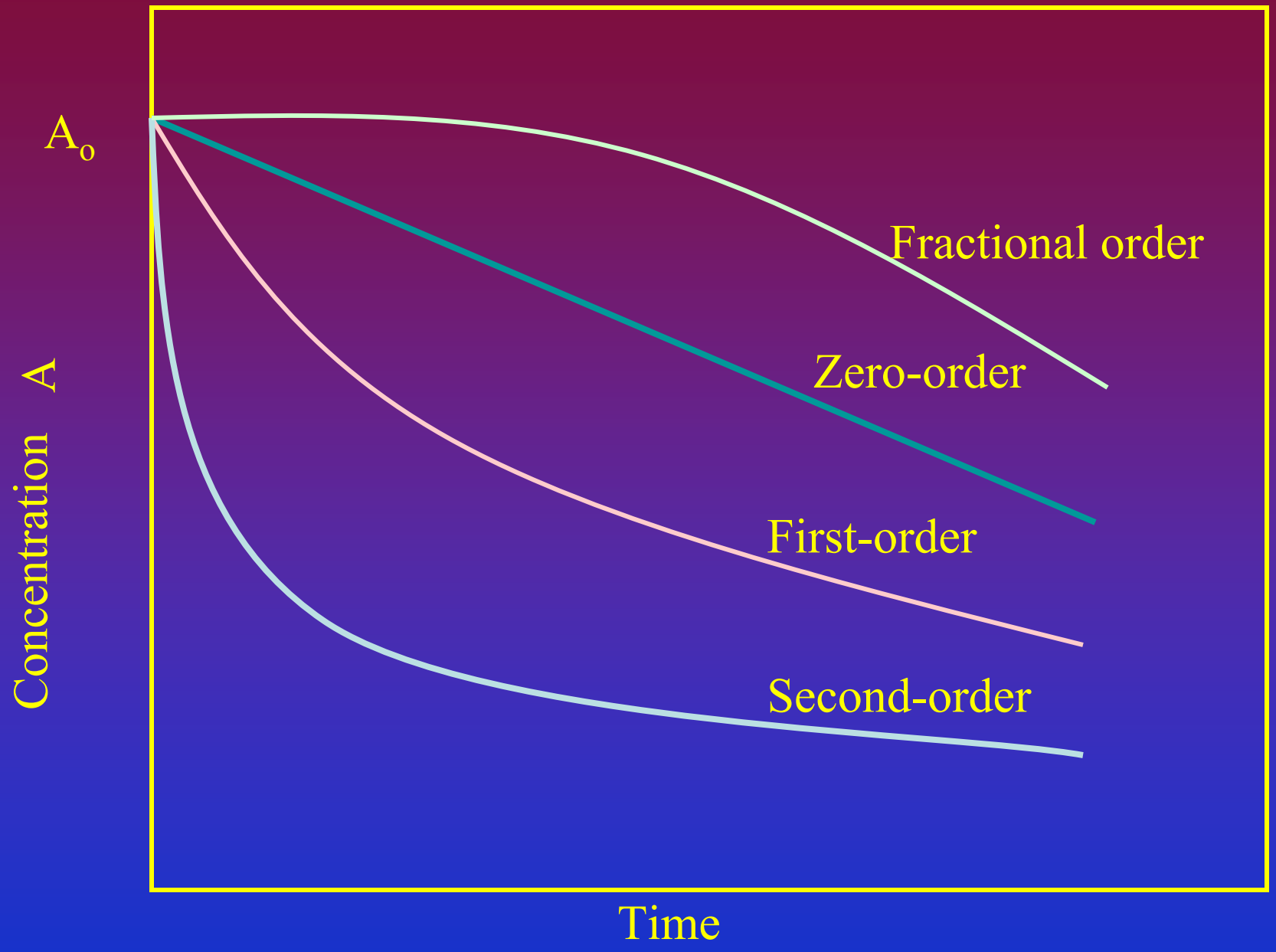
Modes of Food Deterioration

- Frozen Meats, Poultry, and Seafood
  - Rancidity
  - Toughening (protein denaturation)
  - Discoloration
  - Desiccation (freezer burn)
- Frozen dairy products (e.g ice cream)
  - Iciness (recrystallization of ice crystals)
  - Sandiness (lactose crystallization)
  - Loss of flavor
  - Disruption of emulsion systems

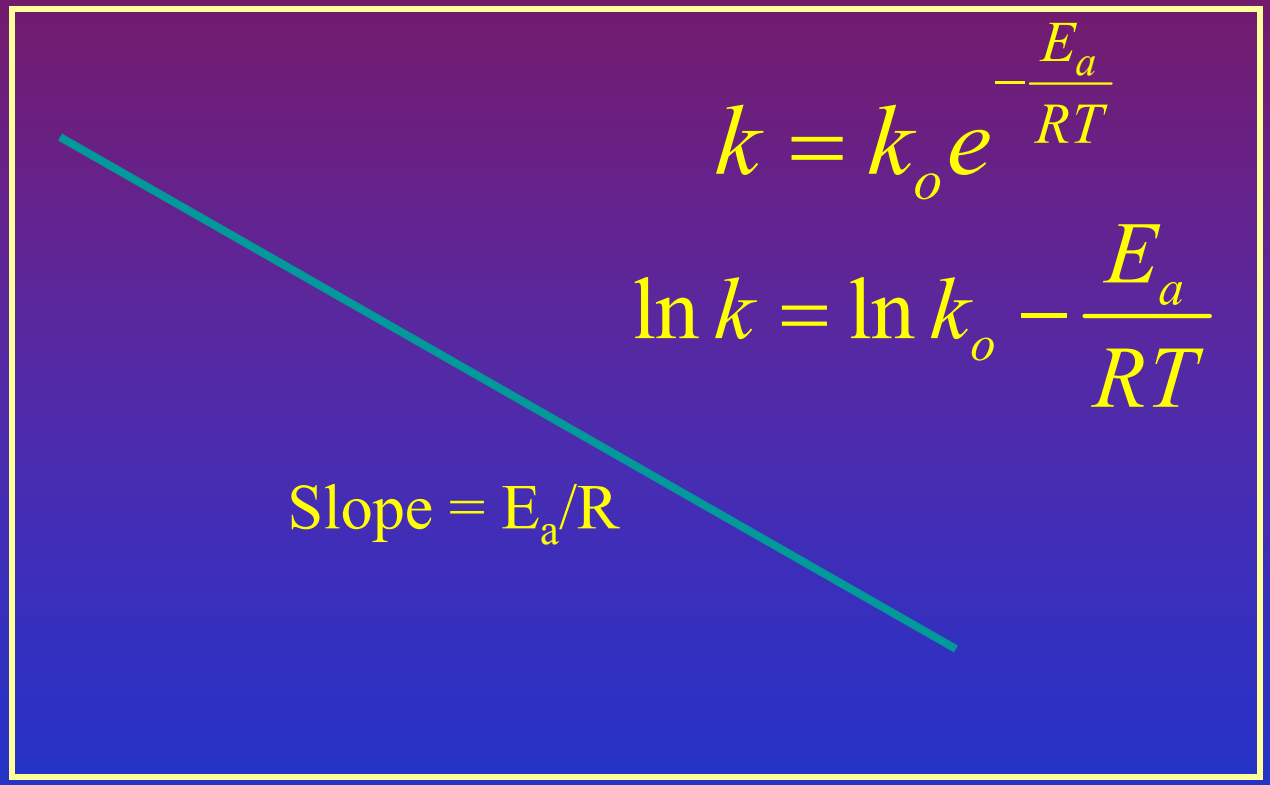
Modes of Food Deterioration

- Frozen Convenience Foods
  - Rancidity in meat products
  - Weeping and curdling of sauces
  - Loss of flavor
  - Discoloration
  - Package ice
- Frozen bakery products (raw dough, bread)
  - Burst can (upon temperature abuse) dough
  - Loss of fermentation capability (dough)
  - Staling (becoming leathery)
  - Loss of fresh aroma

Kinetic Models



Temperature Dependence of Quality Change



Storage of Frozen Foods – Costs vs. Quality Loss